DESIGN MEMORANDUM

ON

CAPE COD CANAL, MASSACHUSETTS

EAST ENTRANCE

REHABILITATION OF BREAKWATER

U. S. ARMY ENGINEER DIVISION, NEW ENGLAND

CORPS OF ENGINEERS

WALTHAM, MASSACHUSETTS

16 MAY 1962

U. S. ARMY ENGINEER DIVISION, NEW ENGLAND
CORPS OF ENGINEERS
424 TRAPELO ROAD
WALTHAM 54, MASS.

ADDRESS REPLY TO:
DIVISION ENGINEER

REFER TO FILE NO.
NEDGW

16 May 1962

SUBJECT: Design Memorandum on Rehabilitation of the Breakwater at Cape Cod Canal, Sandwich, Massachusetts (Minor Rehabilitation)

TO: Chief of Engineers
ATTN: ENGCW-E
Department of the Army
Washington 25, D. C.

1. In accordance with EM 1110-2-1150, 1151 and 1152 Engineering and Design, Definite Project Studies, dated 15 January 1962 and letter ENGCW-E, dated 24 August 1960, Subject: Rehabilitation Projects - Definite Project Studies, there are inclosed ten (10) copies of the design memorandum on the subject project. The work involved is the repair of the breakwater at the east entrance to the Cape Cod Canal, Massachusetts, the cost of which falls within the scope of projects defined as minor rehabilitation projects.

2. In accordance with the above-referenced authority, the design memorandum is forwarded for review and approval. Funds in the amount of $350,000 allocated in FY 1962 are sufficient to undertake the work. Present schedule contemplates advertisement of the project on 25 May 1962 in order to permit obligation of available funds within the fiscal year.

1 Incl (10 cys)
as

OTTO J. ROHDE
Colonel, Corps of Engineers
Acting Division Engineer

U. S. ARMY ENGINEER DIVISION, NEW ENGLAND
CORPS OF ENGINEERS
424 Trapelo Road
Waltham 54, Mass.

NEDGW

16 May 1962

DESIGN MEMORANDUM ON CAPE COD CANAL,
MASSACHUSETTS - EAST ENTRANCE -
REHABILITATION OF BREAKWATER

PERTINENT DATA

1. Location and Purpose. - The east end of the Cape Cod Canal is protected from wave action and littoral drift by a breakwater and a jetty which extend from shore parallel to the Canal. Storms and waves have damaged both, and rehabilitation of the breakwater is needed to continue protection of the canal entrance and vessel traffic.

2. Type of Improvement and Design. - The breakwater is constructed of stone riprap. Rehabilitation using heavier stone is proposed. The design wave is an 11-second wave, 20.5 feet high from the northeast. The normal tide is 9.4 feet, storm tide is 11 feet. Design features are as follows:

		Top		Side Slopes		
Canal Station	Length	Elev.	Width	Channel	Sea	Stone Size
Breakwater:						
10+00 to -6+00	1,600'	18'	25'	1 on 1	1 on 2	3- to 6-ton *
-6+00 to -14+00	800'	18'	20'	1 on 2	1 on 2	6-ton
-14+00 to -15+25	125'	18'	25'	1 on 2	1 on 2	12-ton
End Slope	-	-	-	1 on 3	1 on 3	12-ton
	2,525'					

* Original Design.

3. Principal Quantities and Costs. - The volumes of stone required and estimated costs are:

	Rehabilitation of Breakwater
Stone Required (6 to 12 tons)	19,100 Tons
Construction Cost	$ 320,000
Annual Charges (50-year life)	
Interest & Amortization	$ 13,000
Maintenance	2,000
Total	$ 15,000

4. Benefits. - Prevention of vessel damage and loss of life, and protection of the canal entrance.

PROJECT AUTHORIZATION

5. Section 2 of the River and Harbor Act, adopted 21 January 1927, provided for the purchase of the Cape Cod Canal from the Boston, Cape Cod and New York Canal Company, which had built it between 1909 and 1916 and was operating it as a toll canal. The United States assumed ownership 31 March 1928. Modifications of the Federal project were authorized by Public Works Acts of 1933 and 1935, by River and Harbor Acts of 1935, 1945 and 1958 and by the Chief of Engineers in 1947. In general the project provides for a sea level canal 32 feet deep, 540 feet wide in a 7.7-mile land cut and having a total length of 17.5 miles from Cape Cod Bay to Buzzards Bay. The project includes operating facilities, mooring basins for large and small vessels, a small-boat channel in Onset Bay, as well as two high level highway bridges and a railroad lift bridge.

6. Federal project costs to 30 June 1961 were as follows:

	New Work	Maintenance	Total
Canal Purchase	$11,500,000	--	$11,500,000
	20,069,342 *	$18,634,738	38,704,080
	$31,569,342	$18,634,738	$50,204,080

* Includes $6,138,157 from public work funds and $4,849,700 from emergency relief funds.

7. In addition to the above, the amount of $48,000 was expended from non-Federal contributed funds. The project has been completed as authorized with the exception of an enlargement of the East Boat Basin for small craft.

8. A breakwater and jetty at the east end of the canal were included in the purchase price for the canal properties. There appear to have been no maintenance costs for either structure.

INVESTIGATIONS

9. History of the Breakwater and Jetty. - Construction of the Cape Cod Canal was started in 1909. Apparently the need for some structure at the east end of the canal where it crosses the almost straight shore line of Cape Cod Bay was evident from the start, because a contract for construction of a 3,000-foot breakwater was let 15 May 1909. This contract was completed in 1913 by the Degnon Cape Cod Canal Construction Company. In that year a second contract was let to the same company, apparently for construction of the jetty. On this assumption, the volumes and costs were:

Breakwater	310,782 tons @ $1.50/ton -	$466,173
Jetty	24,866 tons @ $1.50/ton -	37,299
Other miscellaneous costs -		605
Total Contract Costs		$504,077

10. There is no record of any maintenance work on either structure. Since 1913, when they were completed, storms have damaged the tips of both the breakwater and the jetty, and the top of the jetty has been broken down. It also appears that there has been some settlement of both structures. The breakwater light, which was established 4 March 1915 on the breakwater at about the shore line, was moved 1,600 feet to its present location at Canal Station -14+07 on 25 September 1928. As the original end of the structure was about at Canal Station -15+60, it appears probable that the tip had been damaged at that time and that further damage has occurred since.

11. The breakwater design provided for a crest width of 25 feet at 18 feet above mean low water, with side slopes of 1 on 2 on the northwest side from the top to 12 feet below mean low water, and 1 on 1 below that depth and on the channel side. The structure was to be 3,000 feet long, extending 2,600 feet from shore out to a depth of 32 feet. It does not appear to have been built to that length, but to have been actually constructed to a total length of about 2,700 feet, approximately to the 30-foot depth contour. The breakwater stone was to be not less than three tons with 25 percent six tons from 12 feet below mean low water up and on the outer 10 feet below that depth. The core below 12 feet below mean low water was to be stone of not less than 100 pounds each, with 50 percent 1 ton each. A concrete head 30 feet in diameter about 14 feet deep was to be placed at the tip. However, no evidence of this remains and it is not known if it was constructed.

12. The jetty (also called "sand catcher") was constructed in 1913 with a crest width of 20 feet at 10 feet above mean low water, with side slopes of 1 on 1. It was built to the 6-foot depth contour, a distance of about 600 feet. The end of this jetty was used as the reference point for the canal stationing, all distances being measured west along the canal center line from Station 0+00 opposite the end of the jetty. The stone used in the jetty appears to have been somewhat smaller than that used for the breakwater.

13. Surveys of the jetty and breakwater were made in the period 27 December 1961 to 5 February 1962 when profiles, cross sections, and soundings were taken. The surveys show substantial damage at the breakwater tip and moderate damage along the outer part of the breakwater trunk. An inspection made in April 1962 found no change from conditions when the survey was made.

14. Suitability of Design as Constructed - Project Purpose. The breakwater was constructed to arrest littoral drift, train the tidal current at the canal entrance to prevent shoaling and reduce navigation difficulties. There have been ship accidents near the entrance, but it does not appear that the breakwater or jetty were in any way a contributing factor and it is concluded that the breakwater as constructed does fulfill its purpose.

15. The jetty was constructed to prevent erosion of the shore and reduce shoaling of the canal. There is a recurring shoal near Station 15+00, which may be caused by a hard high spot. Maintenance of this end of the canal does not appear to be a major problem. Maintenance requirements are considered to have increased somewhat in the last 20 years since the jetty top has been below high water. It is concluded that the jetty as designed would fulfill its purpose and that repair could be effectively accomplished under the maintenance program.

16. Suitability of Design as Constructed - Structural. - The breakwater was completed in 1913, and in the 49 years since has been generally stable. The tip, which is exposed to deep water waves, has been flattened from a slope of 1 on 2 to a slope of about 1 on 7. The trunk on the canal side has been flattened from 1 on 1 to about 1 on 2.5. This damage is evidence that the original design was not adequate to prevent damage. It should be noted that the original design was sufficient to fulfill the purpose of the structure for 50 years. It is considered that an improved design to strengthen the top and the outer 700 feet of the trunk would assure at least another 50 years of life with minimum maintenance.

17. Design for Rehabilitation - Breakwater. - Wave refraction studies were made to select a design wave for the breakwater head. The water depth at the head is about 30 feet. The mean range of tide is 9.4 feet and storm tides of 11 feet would not be unreasonable. Therefore, waves up to 32 feet could reach the breakwater if they existed. Wave hindcast data from Technical Memorandum No. 55 for Station B of Cape Cod indicates that the most frequent waves from north to the northeast would have periods of 7, 11 and 15 seconds. Refraction diagrams were drawn for these waves to obtain refraction coefficients. The highest wave would result from 11-second deep water waves from the northeast. The hindcast data shows 20 hours of 20- to 25-foot waves. Applying refraction and shoaling coefficients to a 25-foot wave results in a 20.5-foot wave at the breakwater head.

18. The design was based on the Hudson-WES formula for stone size. Checking the original design indicated that a stone weight of 37 tons should have been used for a 20.5-foot wave and using a K_d coefficient of 2.5 for a non-breaking wave. However, the stone used was 3 tons with 25 percent 6-ton. This difference is considered indicative of the error resulting from use of the Hudson-WES formula when waves overtop the structure. The runup for a 20.5-foot wave would be about 0.9, or 18.5 feet. For no overtopping the structure would have to be built to 29.5 feet above mean low water. At the constructed elevation of 18 feet about one-half of the wave would go over the top and the energy expended on the breakwater would be reduced.

19. It is considered that the Hudson-WES formula can be used as a basis for design in this case, because information is available on the stability of the existing structure. There are two possible approaches: derivation of a K_d for the existing structure and using a lower value for a stronger design; or determining the wave height that would have resulted in similar damage on a non-overtopped structure and using that height for design. Both methods were used and appear to yield the same result. However, it is considered that future design studies would be simplified by comparison of K_d coefficients derived for existing structures, whereas there appears to be no comparable basis for reducing wave heights from those computed by present procedures.

20. As constructed, 3-ton stone on the breakwater head with a 20.5-foot design wave would require using a K of 30.6 in the Hudson-WES formula. The original design was not adequate so use of a K_d of 30.6 is not justified for rehabilitation. The present profile in the direction of maximum wave attack is 1 on 6.7, and it appears that the smaller stones have been dislodged leaving stone of about 4.5-ton

minimum. A K_d of 6.1 would suggest this design. However, the present situation is considered to have little or no factor of safety and, therefore, a reduced value for K_d of 5.0 has been chosen for design of rehabilitation of the breakwater head. This value is considered to be comparable to the 2.5 suggested in the Summary of Discussion, Harbor Design Conference, OCE, 5 - 7 December 1960, for non-breaking waves on the head of a non-overtopped structure of rough angular quarry stone. A value higher than 2.5 would be reasonable, since about one-half of the design wave would overtop this structure.

21. Using a K_d of 5 for a 20.5-foot wave would require 18-ton stone on a 1 on 2 slope or 12-ton stone on a 1 on 3 slope. Because placing 18-ton stone on the existing structure would be difficult, the 12-ton stone on 1 on 3 slope was chosen.

22. The original crest elevation appears to be satisfactory, while a lower elevation might increase navigation difficulties. The original head width of 25 feet wide, about 5 stones wide, is considered conservative.

23. A similar approach was used for design of rehabilitation of the trunk between the head and Station -6+00. The original design would require using a K_d of 30.6 on the sea side and 61.2 on the channel side. The present slope is about 1 on 2.5 and is apparently fairly stable with minimum stones of about 4 tons. A K_d of 17.7 would suggest this design for a 20.5-foot design wave. A 20 percent reduction to increase the factor of safety indicates a K_d of 15 to be reasonable. This value is 4.7 times larger than the 3.5 suggested in the Summary of Discussion, Harbor Design Conference, OCE, 5 - 7 December 1960, for non-overtopped structures with wave attack normal to the structure. Because structure would be overtopped by one-half the design wave, and because wave attack would be oblique to the trunk at a low angle (20 to 30 degrees), this value is considered reasonable. (It might be argued that the design wave should be reduced because of the low angle of attack, but there does not appear to be any reasonable way of determining what the reduction should be. A lower wave would result in the same design change although lower K_d values would be indicated. Whatever numbers are used, a K_d for the new design that is 20 percent lower than indicated by the existing structure will result in improved resistance to wave attack. A 20 percent increase in stability of this structure should substantially reduce future maintenance.)

24. Using the K_d of 15 for the 20.5-foot design wave would require 6-ton stone on a 1 on 2 side slope. The original crest height appears to be satisfactory at 18 feet above mean low water. To reduce the quantity of stone required, the top width could be reduced from the original 25 feet to 20 feet. There appears to be no need for a wider crest so 20 feet was selected for rehabilitation.

25. Between Station -6+00 and the shore end of the breakwater at Station 10+00, the breakwater is not badly damaged. The water depth off the structure is less than 3 feet, so wave attack on an 11-foot storm tide would be limited to 11-foot waves. The breakwater appears stable although the channel side slope has flattened somewhat, the top is somewhat below the design elevation, and there are spots where stones have been dislodged. Volume estimates indicate that 4,250 tons of stone would be needed to rebuild this part of the breakwater to the original design cross section. This work does not appear necessary. The structure has probably reached a stable condition, and the somewhat lower crest elevation does not appear to be important. The top of the breakwater should be reshaped to fill holes and prevent further raveling. While some additional stone may be required, most of this work can be accomplished by rehandling displaced stones. The original design for stone of 3 to 6 tons is considered satisfactory.

26. Necessity for Repairs. - The breakwater and jetty at the east entrance of the Cape Cod Canal protect navigation and prevent shoaling of the canal. Both need repair to assure their continued usefulness. A design for rehabilitation of the breakwater has established the following design dimensions:

	Crest Elevation	Crest Width	Side Slopes	Stone Size
Breakwater				
Head	+18' M.L.W.	25'	1 on 3	12-ton
Trunk: Station				
-6+00 to head	+18' M.L.W.	20'	1 on 2	6-ton
+10+00 to -6+00	Reshape existing structure			3- to 6-ton

LOCAL COOPERATION

27. Local cooperation is not required by the authorization for the Canal project.

LOCATION AND TRIBUTARY AREA

28. The Cape Cod Canal is a sea level waterway between Cape Cod Bay and Buzzards Bay, Massachusetts, that eliminates the need for vessels up to 33-foot draft to pass outside Cape Cod. For small vessels, it is the only safe coastal route. It is a shorter and less dangerous route for larger vessels traveling between points south of Portland, Maine, and north of Delaware Bay. The breakwater that is the subject of this design memorandum is located in the Town of Sandwich at the east entrance to the Canal on the shore of Cape Cod Bay.

29. The Canal traffic amounted to 8,600 vessels westbound and 9,200 vessels eastbound in 1959. Waterbourne commerce for that year was 12,600,000 tons, plus 2,300 passengers. The tributary area for the Cape Cod Canal could be said to extend along the Atlantic coast from Maine to Maryland.

PROJECT PLAN

30. The project plan consists of rehabilitation of the existing breakwater at the eastern entrance of the Cape Cod Canal by placing stone riprap to restore and strengthen it as described in paragraph 26 above and shown on the attached plans and cross sections.

31.

COST ESTIMATES

31. The estimate of cost for rehabiliation of the breakwater is based on the volume of stone required to achieve the design dimensions as determined by cross-section surveys made December 1961 to February 1962, and unit prices obtained for similar work in 1961 and 1962. The volume of stone required is as follows:

	12-ton Min.	6-ton Min.	Total
Breakwater	8,100 tons	11,000 tons	19,100 tons

Project Cost

	Breakwater
Contract @ $14/ton	$268,000
Contingencies	27,000
	$295,000
Engineering & Design	3,000
Supervision & Administration	22,000
TOTAL (May 1962)	$320,000

32. No maintenance work has been done since the structure was built. Maintenance to the original design would require about 18,000 tons of stone for the breakwater, equivalent to an annual average of 360 tons. This average would be substantially reduced by the stronger design proposed for rehabilitation, so that future annual maintenance requirements are estimated at 100 tons for the breakwater. The average annual costs are estimated at $2,000.

SCHEDULE FOR DESIGN AND CONSTRUCTION

33. Field investigations were completed in February 1962. Design studies are complete. Preparation of standard plans and specifications is underway and is scheduled to be completed at the end of May when the invitation for bids is to be issued. Construction is scheduled to begin 1 July 1962. Based on placing 5,000 tons of stone a month, the structure would be completed in 4 months.

34. Funds allocated for rehabilitation amount to $350,000.

BENEFITS

35. The breakwater and jetty at the east entrance of the Cape Cod Canal protect the Canal from littoral drift and wave attack and protect vessel traffic by training tidal currents. Canal traffic amounts to nearly 18,000 vessel trips annually, with waterbourne commerce averaging over 12,000,000 tons. Reconstruction of the breakwater is required to prevent further damage to it and to protect the breakwater light. Further damage would substantially increase navigation difficulties for traffic using this heavily traveled waterway. Effectiveness of the jetty in preventing littoral drift into the Canal has been impaired but can be restored under the maintenance program.

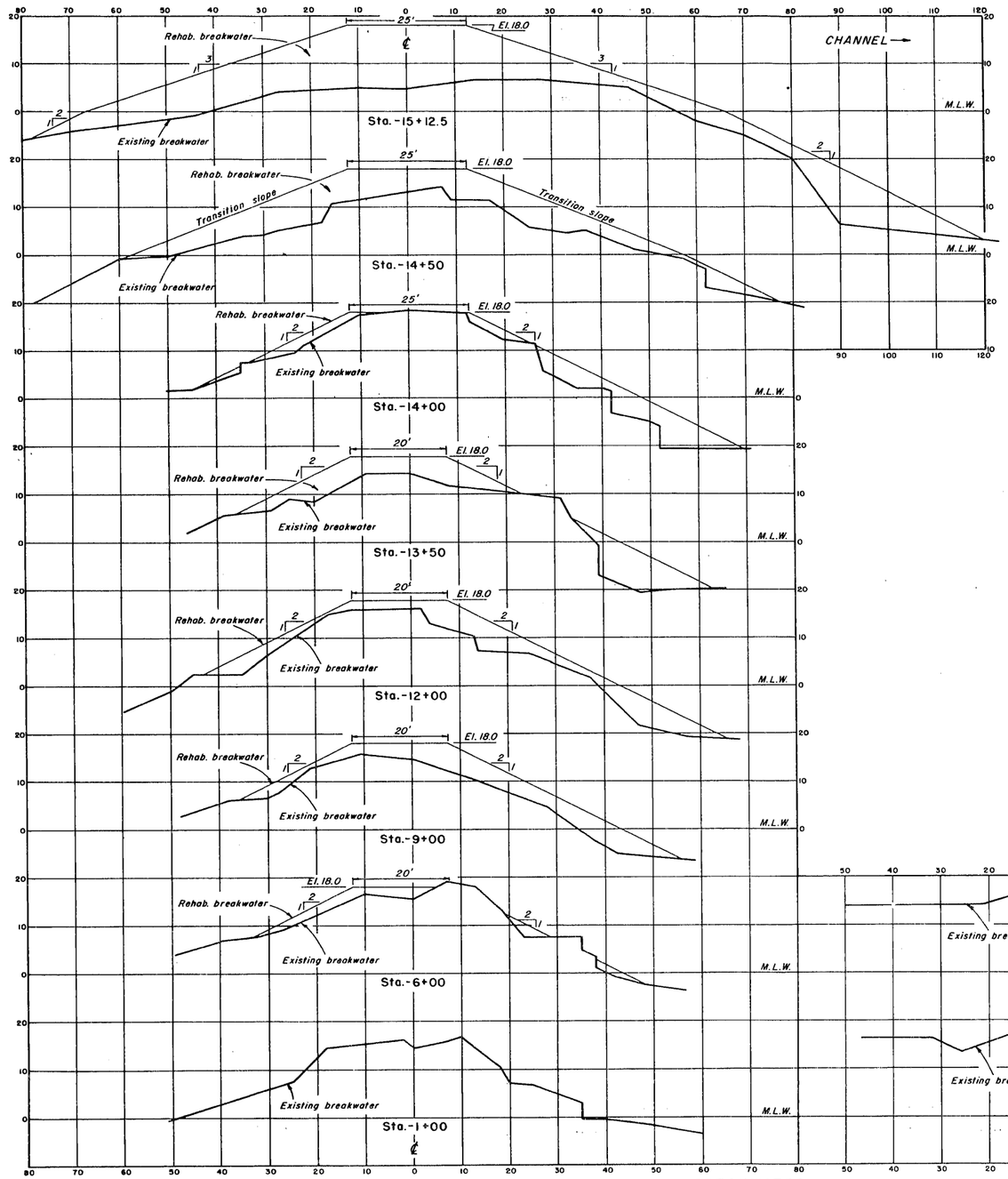
36. The average annual interest and amortization charges for the $320,000 cost of rehabilitation of the breakwater over a project life of 50 years at 2.625 percent, or $20,500, plus future annual maintenance costs estimated at $2,000, make the total annual charges for rehabilitation of the breakwater $15,000. These annual costs are considered well justified in view of the substantial benefits from continued maintenance of a safe entrance to the Cape Cod Canal.

RECOMMENDATION

37. It is recommended that the breakwater at the east entrance of the Cape Cod Canal be rehabilitated as discussed and shown on the project plans.

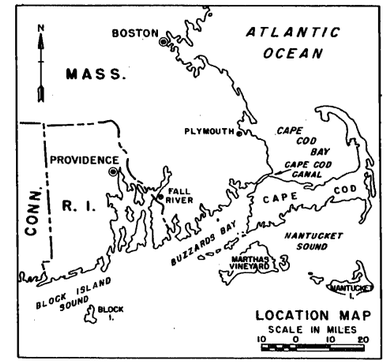
CORPS OF ENGINEERS

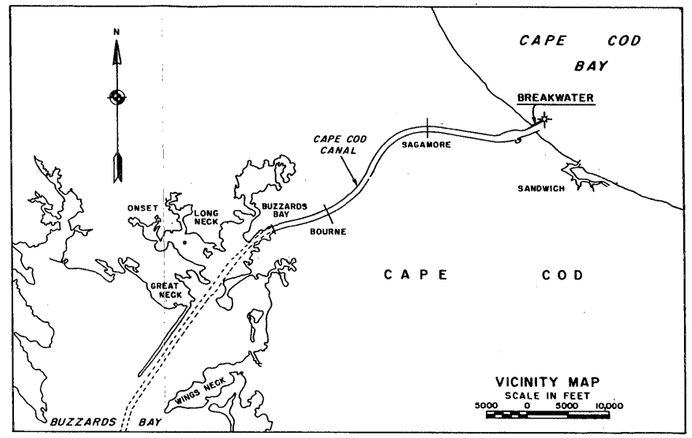
U. S. ARMY



SECTIONS - BREAKWATER

SCALE 1"=10'





NOTE:
For profile, plan and notes, see Sheet No. 2

REVISION	DATE	DESCRIPTION	BY

U.S. ARMY ENGINEER DIVISION, NEW ENGLAND
CORPS OF ENGINEERS
WALTHAM, MASS.

DR. BY	TR. BY	CK. BY
A.L.D.	A.L.D.	

PROJECT ENGINEER

CHIEF, R. & H. SECTION
SUBMITTED BY

CHIEF, PLANS & RPTS. BRANCH

CAPE COD CANAL, MASS.

REHABILITATION OF BREAKWATER

APPROVED

DATE MAY 1962

CHIEF ENGINEERING DIV.

TO ACCOMPANY
DESIGN MEMORANDUM
DATED MAY 16, 1962

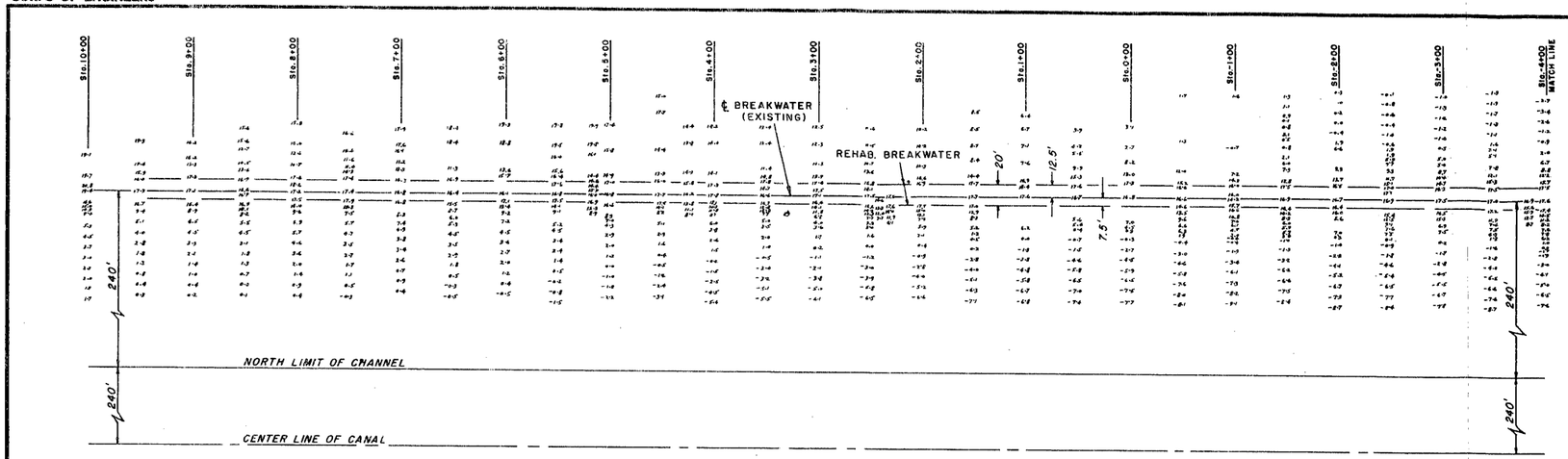
SCALE 1"=10' | SPEC. NO CIV ENG.-18-018-

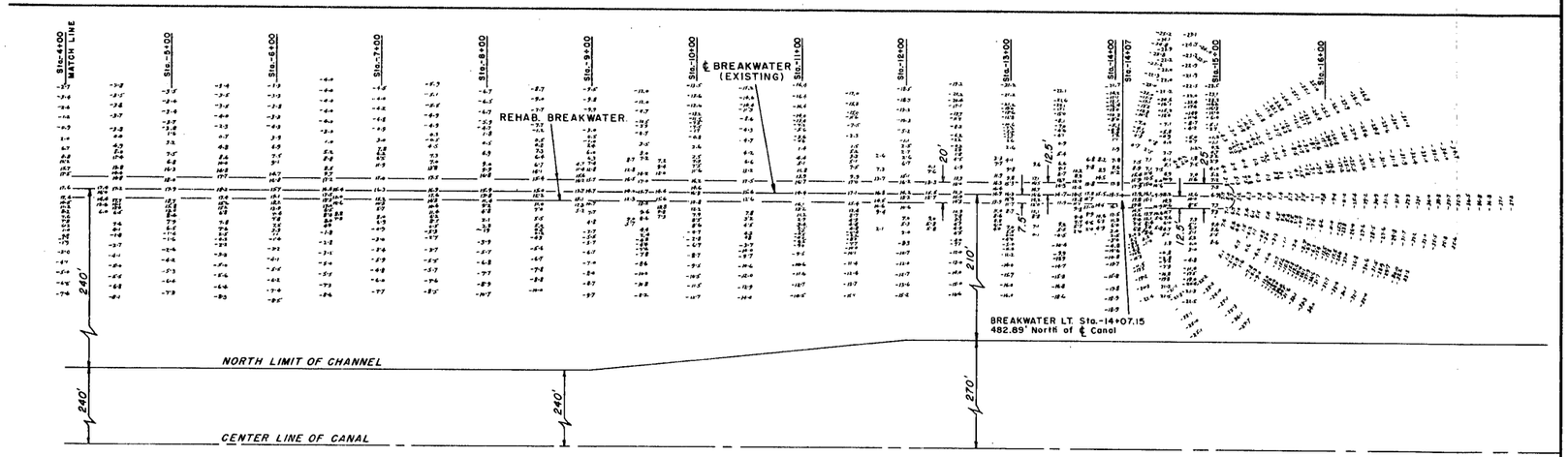
DRAWING NUMBER
1143 E-2-2

SHEET 1 OF 2

CORPS OF ENGINEERS

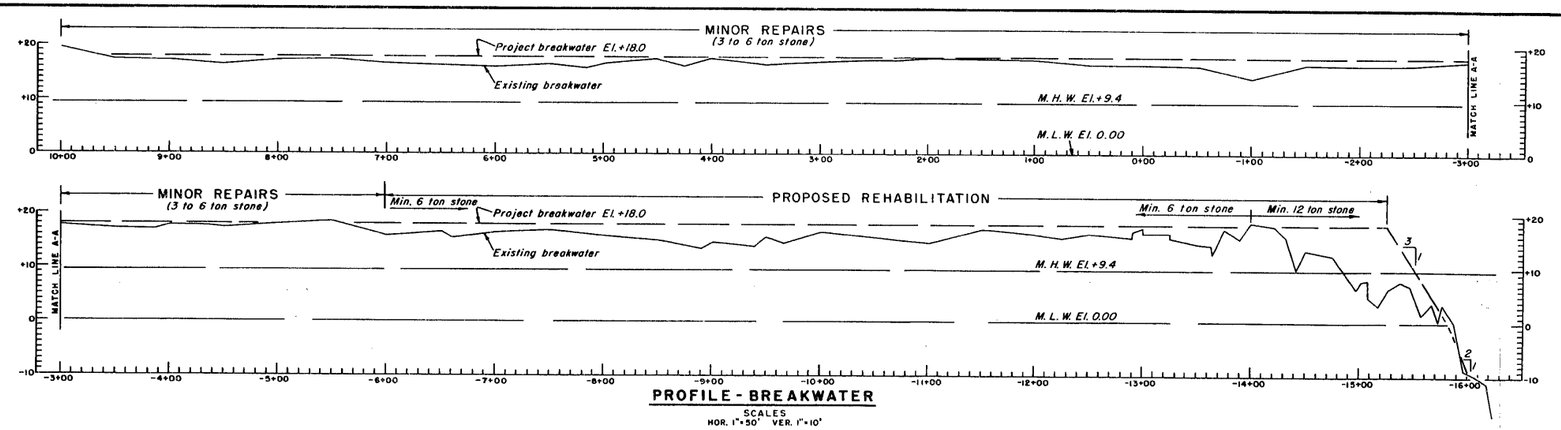
U. S. ARMY





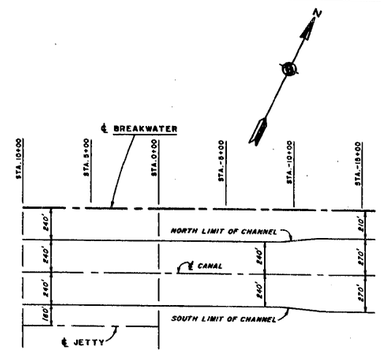
PLAN - BREAKWATER

SCALE 1"=50'



PROFILE - BREAKWATER

SCALES
HOR. 1"=50' VER. 1"=10'



GENERAL PLAN

SCALE 1"=400'

NOTES:

Elevations are in feet and tenths and are referred to the plane of Mean Low Water.

Survey of Dec. 27, 1961, Jan. 3-16 and Feb. 5, 1962 by H.S. Ormrod, Cape Cod Canal Office.

B.M. for breakwater, Sta. 9+00 (480' north of center line of Canal). El. 17.04' above M.L.W.

Elev. above M.L.W. shown thus: 4.8; below M.L.W. shown thus: -4.8.

See Sheet No. 1 for sections.

REVISION	DATE	DESCRIPTION	BY

U.S. ARMY ENGINEER DIVISION, NEW ENGLAND
CORPS OF ENGINEERS
WALTHAM, MASS.

DR. BY	TR. BY	CK. BY
A.L.D.	A.L.D.	[illegible]

PROJECT ENGINEER

CHIEF R. & H. SECTION

SUBMITTED BY

CHIEF, PLAN. & RPTS. BRANCH

CAPE COD CANAL, MASS.

REHABILITATION OF BREAKWATER

APPROVED DATE MAY 1962

CHIEF ENGINEERING DIV.

TO ACCOMPANY
DESIGN MEMORANDUM
DATED MAY 16, 1962

SCALE AS SHOWN SPEC. NO. CIV ENG.-19-016-

DRAWING NUMBER
1143 E-2-2

SHEET 2 OF 2